MARKAL Modeling Environment and Regionalization

Chip Friley
Brookhaven National Laboratory
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pfriley@bnl.gov

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AGENDA

- **Development of the MARKAL family of models**
- How the MARKAL model works
- Regionalization and the MARKAL model

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Introduction to the MARKAL Family of Models

- MARKAL is a long-term technology specific energy system optimization model.
- Identifies the most cost-effective pattern of resource use and technology deployment over time.
- Quantifies the sources of emissions and waste flows from the associated energy system.
- Provides a framework for evaluating alternative futures, and role (cost-benefit) of various technologies, trade and policy options.

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Introduction to the MARKAL Family of Models

- Early development at Brookhaven National Laboratory (BNL):
  - Reference Energy System network concept (1975)
  - Brookhaven Energy System Optimization Model (BESOM) and its variants (Time sequenced TESOM, Regional RESOM) (1976 – 1978)
- Implementing Agreement under the auspice of the International Energy Agency – Energy Technology Systems Analysis Programme (IEA-ETSAP) to develop new modeling framework (1978 - 2001)
- BNL/KFA Parallel OMNI/Fortran Development Teams produce first production MARKAL model (1980)
- Subsequent development has resulted in many model improvements and several distinct model variants

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Who Is Using MARKAL; and Why?

- More than 90 Research institutions and universities in over 50 countries around the world; to look at sustaining economic development in the context of energy/environmental issues ranging from Climate Change to local air pollution.
- Research institutions in the 16 countries currently participating in the IEA – Energy Technology Systems Analysis Programme (ETSAP); to support their national governments' energy/environmental planning. *(WWW.ETSAP.ORG)*
- The International Energy Agency (IEA) for the Energy Technology Perspective (ETP) project; to bring technology detail to future ***World Energy Outlook*** publications.
- Development of SAGE by the U.S. Energy Information Administration for the International Energy Outlook

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MARKAL Model Overview

- MARKAL is a technology rich, dynamic linear programming model that solves for sector specific, fuel and technology choice over 5-year intervals.
- MARKAL model structure is generic; it can easily accommodate any set of demand specifications and technologies.
- The model solves for the combination of specific energy technologies that satisfies energy service demands at minimum cost.
- It provides an integrated energy, economic, and environmental analysis.
- The model has a long history of use for energy system analysis and a large international user community. The reference energy system (RES) approach has been tested and refined over the past 20+ years.

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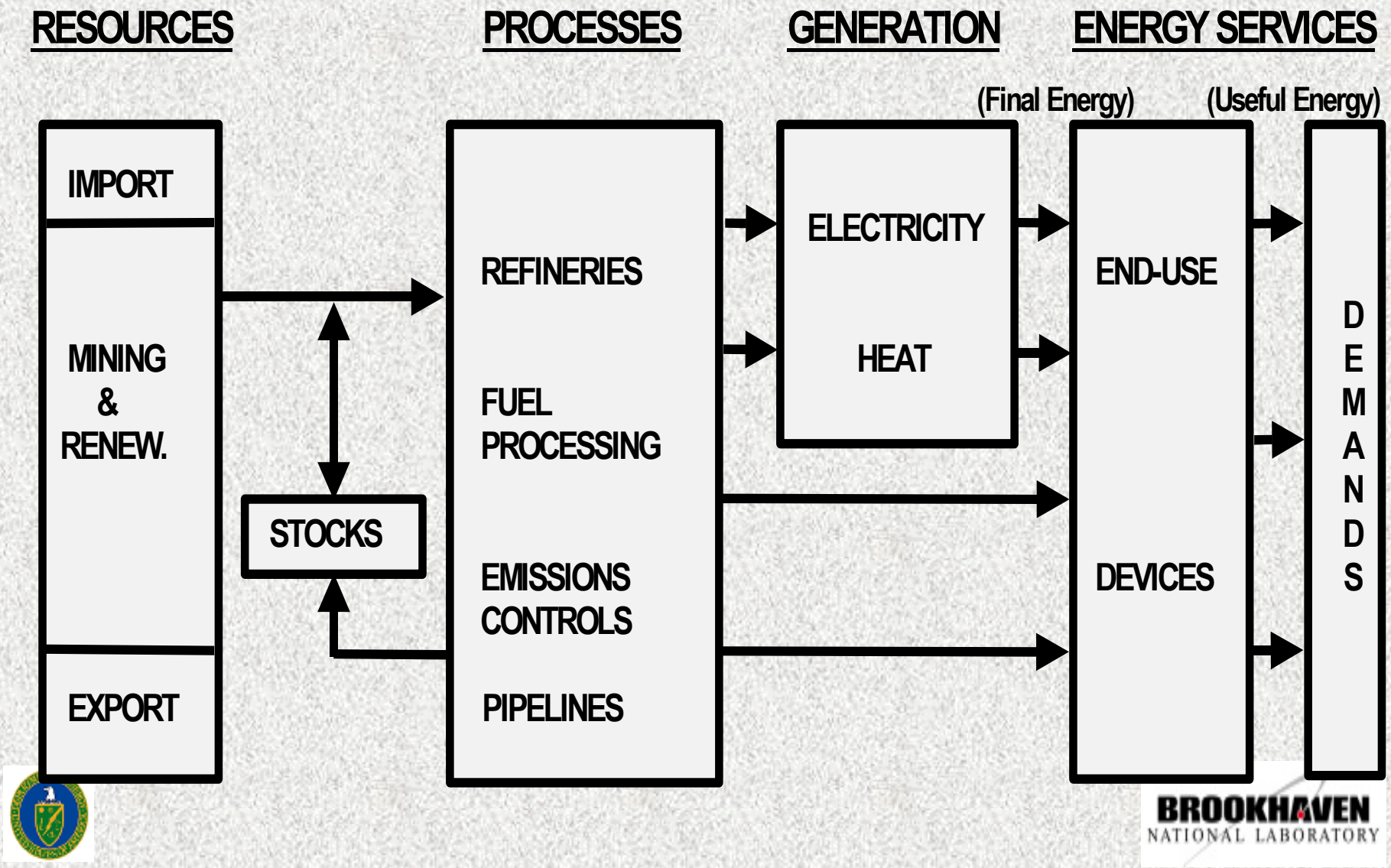
MARKAL Building Blocks

The Reference Energy System



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Technology Choice

Technology Characteristics
- Energy Sources Used
- Efficiency
- Costs (Capital and O&M)
- Availability

Energy Resources
- Cost and Availability

Energy Service Demands
- By Sector/Region

Other Assumptions
- Long-Term Discount Rate
- System Reserve Requirements

Other Constraints
- Max. CO_2 Emissions by Time Period

→ **Dynamic LP Optimization**

→ **Technology Mix for Each Time Period That Satisfies Energy Demand Given Constraints**

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Regionalization Within MARKAL

- Use a multi-region MARKAL variant (i.e. SAGE or ETP) as template for a regional U.S. MARKAL model
- Demand side disaggregation can be done by adding new service demands
  - Separate regional service demands for residential space heating and cooling
  - Separate service demands for rural and urban/suburban LDV VMTs
- Supply Side disaggregation can be done by creating a step function to differentiate regional production or transmission costs
  - Aggregate development and O&M cost assumptions for 51 separate geothermal sites into two separate five-step supply curves for dual flash and binary cycle systems
  - Represent differences in transmission or delivery costs by a similar step function.

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